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THE EFFECT OF INTERNAL SURFACE DEFECTS ON SULPHIDE STRESS CRACKING SUSCEPTIBILITY OF A CONVENTIONAL LINE-PIPE STEEL

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THE EFFECT OF INTERNAL SURFACE DEFECTS ON SULPHIDE STRESS CRACKING SUSCEPTIBILITY OF A CONVENTIONAL LINE-PIPE STEEL

by

I.C.G. Ogle

ABSTRACT

Specimens representative of a Grade 52 ERW pipeline, both with and without a type of internal defect known as a "roll mark", were tested under 3-point loading for susceptibility to cracking during a 200-hr immersion in an acidified, aqueous, saline solution saturated with H_2S. The effect of roll marks on cracking was investigated by testing specimens at various stresses, as determined by strain gauge calibration, and by comparing the threshold stress for edge crack formation in both sets of specimens.

The type of damage exhibited by specimens following test exposures was of a type known as hydrogen induced step-wise cracking. At none of the stress levels investigated did the presence of a roll mark affect either the initiation of delaminations or the initiation and propagation of the step-wise linkage of delaminations.

A threshold stress of 107% S.M.Y.S. was determined, above which some brittleness of the step-wise linkage of delaminations was apparent as evidenced by the appearance of edge cracks. In spite of the stress-sensitive nature of the damage process at high stresses, no effect of defects on threshold stress was found.

INTRODUCTION

This research was initiated as a result of information provided to PMRL by the National Energy Board concerning the internal surface condition of one particular section of line pipe. It has become apparent that certain internal surface defects, known as "roll marks", can be present, yet not cause that section of line pipe in which they occur to be rejected. Such defects, on the basis of information given by the NEB[1], are typically short fissures oriented in the rolling direction and of a depth less than 0.2 mm (0.008 in.). Their presence on the inner surface of a line destined for sour gas service could, by way of increasing the susceptibility to sulphide stress cracking (SSC), endanger the integrity of the line.

Current CSA[2,3] and NACE[4] specifications governing use of line-pipe steels in sour environments restrict hardness and yield strength of such steels to R_C 22 and 552 MPa (80 ksi), respectively. Pipe manufactured to 5LX-52 specifications has a hardness and yield strength well below these guidelines. However, as reviewed by Carter[5], prior cold work, such as might be associated with roll marks, has a deleterious effect on a material's resistance to SSC as does the presence of notches since they act as stress raisers. Also to consider in relation to the present study are the numerous cases, quoted by Carter[5], of apparent SSC failures in the laboratory of steels of yield strength as low as 276 MPa (40 ksi).

Recent research[6,7] has provided evidence that the apparent SSC failures of steels in this strength range occur, in fact, by hydrogen induced step-wise cracking. The mechanism by which this H_2 damage process takes place involves sub-surface delamination at internal interfaces, such as inclusions, with concomitant step-wise cracking causing linkage of the delaminations. The mechanism is generally considered to be independent of applied stress. Consequently, laboratory tests designed to indicate susceptibility of steels to this form of damage[7]

currently consist of immersion of unstressed specimens in an appropriate environment.

On the basis of the present knowledge of SSC and hydrogen induced step-wise cracking, the following questions must be posed as to the effect of roll marks on pipe integrity. For example, is there sufficient cold work and stress intensification associated with roll marks in the conventional Grade 52 line to effect brittle SSC initiation? If brittle SSC does not occur, then does the presence of roll marks influence the frequency and distribution of hydrogen induced step-wise cracking? The present study is designed specifically to answer these questions in an attempt to evaluate "suitability for sour service" of this Grade 52 line assuming the presence of defects such as roll marks.

EXPERIMENTAL

1. Materials

The source of material for all test specimens was a supplied section of pipe, approximately 1 m (39.37 in.) in length, which contained numerous roll marks supposedly representative of those detected in other joints of the particular Grade 52 ERW pipeline, 406 mm (16 in.) O.D. and 5.6 mm (0.219 in.) wall thickness. The corrosion test specimens, 114 mm (4.5 in.) in length by 12.7 mm (0.5 in.) in width and of full pipe wall thickness, were cut transverse to the pipe axis. The location of each defect-containing specimen in the pipe was determined so that a roll mark, as detected by a fluorescent dye penetrant test, was situated at specimen mid-length. Defect-free specimens were cut from random locations of the pipe section. Tension test specimens were cut from defect-free pipe locations and machined to ASTM A-370 specifications.

2. Methods

The SSC test consisted of a 200-hr immersion of specimens, which had previously been loaded under 3-point loading to predetermined strains, in H_2S saturated 3.5% NaCl solutions acidified

to an initial pH of 28 by addition of 0.5% $HC_2H_3O_2$. Specimens both with and without centrally located roll marks were tested in this manner, initially at 3% strain, then at progressively lower strains until no cracking was evident.

All specimens were loaded as illustrated in Fig. 1 so that the inside pipe surface was in tension. Electrical isolation of each specimen from the stainless steel loading jig and fixtures was ensured by the use of a polyethylene washer and sleeves on the loading bolt and fixed end pins, respectively. Calibration of bending strains was performed with the loading apparatus shown in Fig. 2 by relating, for a defect-free specimen, the deflection at specimen mid-length to maximum bending strain. The former parameter was measured to 0.0025 mm (0.0001 in.) by a dilatometer gauge while the latter was monitored by use of a strain gauge mounted at specimen mid-length. This procedure was adopted because of the irreproducibility of maximum bending strains predicted by less time-consuming methods[8,9]. Judgment of whether specimens had or had not cracked during the test period was based on the presence or absence of macroscopic crack propagation on both specimen edges in the thickness direction. Discussion of this choice of criterion appears in the following section.

In addition to obtaining mechanical pipe properties from the flattened tensile specimens, stress-strain behaviour was recorded to greater than 1% extension. This was performed so that bending strains at which specimens were tested for SSC resistance could also be expressed as engineering stresses.

RESULTS AND DISCUSSIONS

1. Effects of defects on threshold stress for initiation of brittle SSC

Figure 3 illustrates typical response to the SSC test of specimens cut from the pipe for which mechanical properties are given in Table 1. Longitudinal sectioning of specimens which exhibited edge cracks in most cases did not reveal internal cracking.

Internal cracks such as are depicted in Fig. 4 were reproducibly observed only in specimens tested at 2% strain or greater. Even in these particular cases, the crack extended across only a small proportion of the specimen width. Because of the difficulty in detecting internal cracks, the presence or absence of edge-cracking was selected to be the most reliable stress-sensitive criterion for judging susceptibility of specimens to SSC at any given bending strain.

The results listed in Table 2 indicate that the presence of a roll mark such as illustrated in Fig. 5 had no significant effect on the threshold stress for initiation of edge cracking. The absolute value of the threshold stress, approximately 107% of the specified minimum yield strength (S.M.Y.S.), errs on the conservative side for two reasons apart from consideration of the severe test environment: (1) tensile stresses at the edge of a beam during bending are somewhat higher than those at mid-width; and (2) nature of the cracks observed suggests that initiation and propagation would occur more readily at the specimen edge than internally.

To expand on this latter reason, all internal cracks detected in the region of the bend apex were similar to that shown in Fig. 4. As such, all were associated with a delamination on the low stress end and a pit on the surface or high stress end. Edges of specimens were heavily corroded in the form of pits elongated in the rolling plane. Thus, a similar type of damage to that apparently required for internal initiation and propagation of cracks occurred with much greater frequency on specimen edges. One might then expect edge cracks to initiate and propagate more readily and possibly have a lower threshold stress than those which formed internally.

The lack of effect of roll marks on threshold stress was also evident on metallographic examination, subsequent to test immersions, of sections containing defects. Figure 6 shows a section of a roll mark beneath which no indication of cracking was found following the examination of several sections through the defect.

This specimen, tested at 3% strain, did however exhibit cracking of the type depicted in Fig. 4.

2. Effect of defects on hydrogen induced step-wise cracking

Specimens were found to be susceptible to a limited extent to hydrogen induced step-wise cracking in the rather severe laboratory test. Evidence of the common form[7] of this type of damage was found on compressive sides and low tensile stress ends of specimens and is shown in Fig. 7. A less well developed network of linked delaminations which occurred at a mid-wall thickness location in the region of the bend apex is pictured in Fig. 8. At this depth beneath the tensile surface, the tensile stress is again much lower than the stress at the surface. In no case was there any evidence that the presence of a roll mark played a role in the formation of internal delaminations.

3. Cracking mechanisms

This study indicates that it is perhaps better to treat the combined effect of brittle SSC and hydrogen induced step-wise cracking rather than either mechanism separately when considering the effect of aqueous H_2S environments on steels in this range of yield strength.

It is apparent from the results that internal blisters or delaminations formed independently of the applied stress. The effect of increased applied stress appeared to be one of an alteration of the mechanism by which linkage of delaminations occurred. For example, above some rather high threshold stress, step-wise linkage adopted some of the characteristics of brittle SSC seen in much higher-strength steels. However, even at these high stress levels, the presence of an internal delamination was the necessary precursor to brittle crack propagation. The presence of a surface stress raiser alone was not sufficient to initiate brittle SSC in the steel studied.

This type of cracking response would suggest that present laboratory techniques, such as the BP test[7], which are employed to indicate the relative susceptibility of steels to hydrogen induced step-wise cracking, should be conducted with the inclusion of applied stress as a variable.

CONCLUSIONS

Exposure of stressed specimens representative of conventional Grade 52 ERW pipe, to an acidified, aqueous saline solution saturated with H_2S caused internal damage of the type commonly referred to as hydrogen induced step-wise cracking.

At none of the above levels investigated did the presence of a roll mark affect either the initiation of internal delaminations or the initiation and propagation of the step-wise linkage of delaminations. Hence, the presence of roll marks on the inner surface of a conventional Grade 52 pipe should not increase the risk of SSC or hydrogen induced step-wise cracking for such pipe when operated in sour service.

This study has provided evidence of the introduction of a brittle component into the step-wise cracking process, resulting in linkage of delaminations, at applied stresses above the approximate threshold of 107% S.M.Y.S. Laboratory tests designed to determine relative susceptibility of steels to hydrogen induced step-wise cracking should, therefore, include applied stress as a variable.

ACKNOWLEDGEMENTS

Test jigs were constructed and experimental trials performed by A. Blouin and D. Linkletter, respectively, of the Corrosion Section. The study was conducted under the general supervision of G.J. Biefer, Head, Corrosion Section.

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Table 1. Mechanical properties of line-pipe steel

Yield Strength		Ultimate	Elongation
0.2% offset, ksi	0.5% extension under load, ksi	Strength, ksi	%
57.7	58.8	73.6	33

Table 2. Cracking behaviour of specimens with and without defects

Defect Absent			Defect Present		
Strain, %	Stress, ksi	Response*	Strain, %	Stress, ksi	Response*
3.0	68.3	F	3.0	68.3	F
2.0	65.0	F	2.0	65.0	F
1.0	61.7	F	0.42	57.4	F
0.8	60.6	F	0.34	56.2	F
0.6	59.0	F	0.33	56.0	F
0.45	57.8	F	0.31	55.5	NF
0.42	57.4	F	0.29	54.8	NF
0.39	57.0	F			
0.36	56.6	F			
0.35	56.4	F			
0.34	56.2	F			
0.33	56.0	NF			
0.30	55.2	NF			

* F - failure; NF - no failure

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Fig. 1. Three-point bending jig, X0.7.

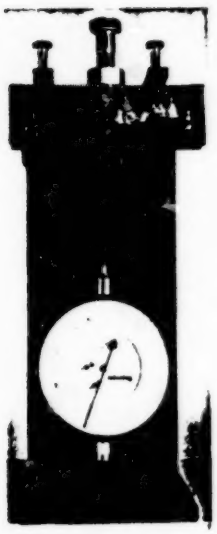

Fig. 2. Loading apparatus, X 1/4.

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Fig. 3. Edge cracking on concave tensile surfaces of specimens strained to 1.0, 0.8, 0.6, 0.45 and 0.30%, top to bottom. X1.2

Fig. 4. Typical association of delamination, crack and corrosion pit, X250.

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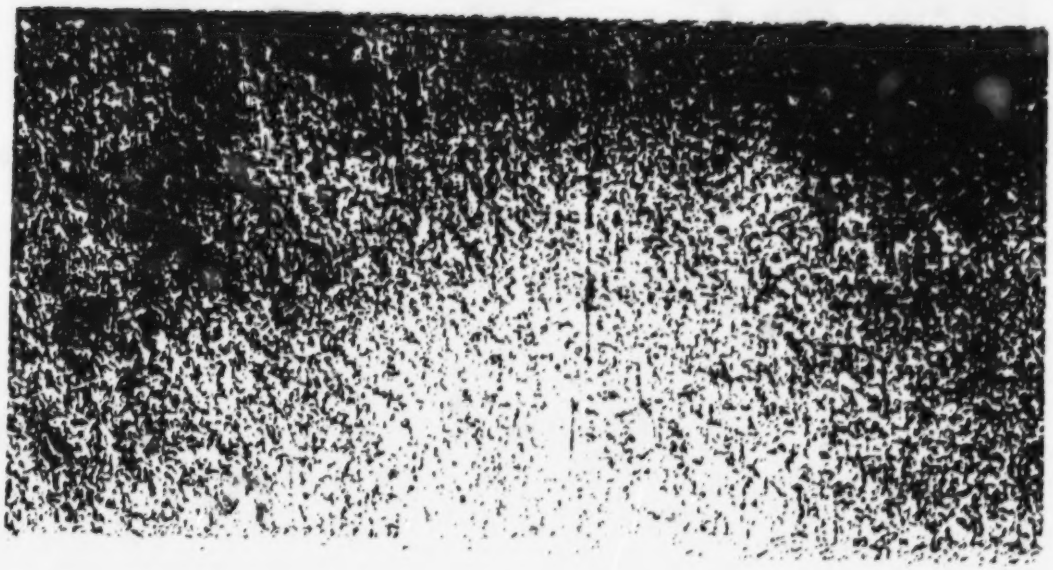

Fig. 5. Typical roll mark centrally located in specimen, X6.

Fig. 6. Cross-section of typical roll mark following 200-hr test at 3.0% strain, X250.

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Fig. 7. Hydrogen induced step-wise cracking at area of low applied stress, X100.

Fig. 8. Hydrogen induced step-wise cracking, mid-wall thickness location at bend apex, X100.

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